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Integrated detection of light propagating in an optical waveguide with a photodetector array fabricated directly on the waveguide surface has been demonstrated. Devices having very good performance were formed by depositing polycrystalline silicon and laser recrystallizing it prior to device fabrication. The use of two lasers has been shown to result in improved recrystallization. An analysis of a four-layer optical waveguide structure has been performed and applied to multiple layer gallium-aluminum-arsenide structures and SiO_2/Si structures. Numerical calculations of waveguide attenuation due to substrate coupling for thermally-nitrided silicon dioxide and for gallium aluminum arsenide waveguides have been performed for a variety of layer thicknesses, layer material compositions, and wavelengths. Comparison with some experimental data has also been carried out. Extensive Raman microprobe characterization has also been performed on laser recrystallized silicon and on GaAlAs dielectric strip waveguide structures. Use of rapid thermal annealing to initiate in-diffusion of Ti into $LiNbO_3$ has yielded low loss optical waveguides.

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Final Report

INTEGRATION OF DETECTORS WITH OPTICAL WAVEGUIDE STRUCTURES

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Table of Contents

I. Summary (Abstract)

Integrated detection of light propagating in an optical waveguide with a photodetector array fabricated directly on the waveguide surface has been demonstrated. Devices having very good performance were formed by depositing polycrystalline silicon and laser recrystallizing it prior to device fabrication. The use of two lasers has been shown to result in improved recrystallization. An analysis of a four-layer optical waveguide structure has been performed and applied to multiple layer gallium-aluminum-arsenide structures and SiO_2/Si structures. Numerical calculations of waveguide attenuation due to substrate coupling for thermally-nitrided silicon dioxide and for gallium aluminum arsenide waveguides have been performed for a variety of layer thicknesses, layer material compositions, and wavelengths. Comparison with some experimental data has also been carried out. Extensive Raman microprobe characterization has also been performed on laser recrystallized silicon and on GaAlAs dielectric strip waveguide structures. Use of rapid thermal annealing to initiate in-diffusion of Ti into $LiNbO_3$ has yielded low loss optical waveguides.

II. Introduction

The present report describes the research accomplished for the contract AFOSR F49620-85-C-0044 entitled "Integration of Detectors With Optical Waveguide Structures." Most of the important results obtained have been or will be published (See Section V for a list of Program publications) so the present report does not contain full detail of all accomplishments. For those wishing more detail in a certain area, specific publications will be referenced throughout this report. It is noteworthy that nine journal papers, ten conference presentations with written proceedings, seven conference presentations with no written proceedings, and five Ph.D. dissertations have resulted from research either fully supported by or partially supported by this grant.

The primary goal of this project has been the investigation of fabrication techniques and materials characterization associated with integrating photodetectors with optical waveguides. High quality photodetectors integrated with optical waveguides have been formed by depositing silicon onto a waveguide surface, laser recrystallizing this silicon, and ion implanting this silicon.[1-3] A major aspect of this program has also involved an investigation of low-loss optical waveguides formed on GaAs and Si substrates. Results in these areas include demonstration of the use of two laser beams (Argon-ion and CO_2 lasers) scanned simultaneously to recrystallize silicon so that it has no residual strain,[4-6] determination of design criteria for multilayer GaAs-GaAlAs optical waveguides and multilayer waveguides formed on silicon,[7] investigation of the use of rapid thermal processing to recrystallize silicon, extensive Raman microprobe characterization of materials involved in the above areas,[8-10] and use of rapid thermal

annealing to initiate Ti in-diffusion into $LiNbO_3$ to form optical waveguides having lower loss than those produced by using only conventional furnace processing.[11,12] We summarize this progress in Section IV of this report.

To support the overall goals of Air Force research, there has been significant interaction between personnel involved in the present and past AFOSR research program and those involved in military programs at the Air Force Avionics Laboratory, Rockwell International, McDonnell-Douglas, Battelle, Motorola, General Dynamics, Lockheed, Honeywell, Amoco Research Center, and Oak Ridge National Laboratory. A number of papers have been co-authored by personnel from several of these institutions with personnel from the University of Cincinnati.

Interaction with personnel at nearby Wright-Patterson Air Force Base has increased during this program. Anthony Servizzi, a graduate student working on this program, has begun to interact with Air Force personnel associated with molecular beam expitaxial (MBE) growth of GaAs-GaAlAs multiple layer samples and related material characterization. He has obtained samples containing multiple quantum wells and is investigating absorption involving quantum well transitions. In addition, Dr. David E. Zelmon, who obtained his Ph.D. in Electrical and Computer Engineering at the University of Cincinnati working on this contract and was advised by Dr. J. T. Boyd, now works for the Air Force Materials Laboratory at Wright-Patterson Air Force Base. Also working in the same group is Dr. F. K. Hopkins who also obtained his Ph.D. in Electrical and Computer Engineering at the University of Cincinnati (1983) and was advised by Dr. J. T. Boyd.

The focal plane disector is a device structure which was originally conceived and first demonstrated by D. A. Ramey and J. T. Boyd of the University of Cincinnati working under AFOSR funding. This concept has been contracted by the Air Force Wright Aeronautical Laboratories (Avionics Laboratory) to the Westinghouse Defense Electronics Center for development and use in optical signal processing systems.

III. Summary of Program Objectives

Research accomplishments at the University of Cincinnati made possible by previous AFOSR funding along with the expertise and laboratory facilities developed provide a sound basis for continued funding of the research carried out. Two major areas of research are being pursued with funding for one Ph.D. student in each area. The first area involves investigation of the formation of photodetectors on optical waveguide surfaces while the second area involves the investigation of low loss optical waveguides on GaAs and Si substrates. The approach being taken for the formation of photodetectors on optical waveguide surfaces involves deposition of polycrystalline silicon onto the waveguide surface, laser recrystallization of this silicon, and fabrication of photodetectors by ion implantation. Being able to integrate high quality photodetectors and photodetector arrays onto any waveguide surface would greatly simplify many integrated optical devices, particularly those utilizing Bragg diffraction, and improve their performance. The approach being taken to form low loss waveguides on multiple layer GaAlAs structures is to carefully design the Al concentration of the various layers to avoid substrate coupling and to form channel-confining structures in cladding layers. Low loss GaAlAs waveguides will allow more widespread use of integrated optoelectronic devices for high speed applications. The approach being followed to form very low loss optical waveguides on silicon substrates is utilizing impurity doping into SiO_2 to increase the refractive index. Optical channel waveguide structures formed on SiO_2/Si substrates having very low values of loss would allow integration of fiber sensors onto Si substrates.

IV. Research Accomplishments

A. Photodetectors on Optical Waveguide Surfaces

We demonstrated early in this program integrated detection of light propagating in an optical waveguide by a photodetector array fabricated directly on the waveguide surface.[1,2] The better performing devices were characterized by:

1. Low reverse pn junction leakage currents of the order of 10^{-12}A.
2. Reverse breakdown voltages of the order of 40-70 volts.
3. Photodetector dynamic ranges of 55-60 dB.

To achieve such good detector characteristics, the deposited silicon was first laser recrystallized. Photodetector p-i-n junctions are formed by ion implantation. We used anti-reflection stripes to confine grain boundaries to regions between detectors.[10] The silicon between detectors which included these grain boundaries was removed by plasma etching. In general, regions which were not laser recrystallized yielded poor characteristics, high reverse leakage currents, no voltage breakdown, and very weak optical response.

Significant effort has been directed at investigating improved methods for recrystallization of silicon. Two techniques which were explored are use of two lasers simultaneously and use of rapid thermal processing. In what follows we summarize first results obtained with two beam laser recrystallization followed by our experience with rapid thermal processing.

In our experiments with two lasers we utilized Ar^+ and CO_2 laser beams scanned simultaneously along the sample. This is in contrast to most conventional recrystallization experiments which utilize an Ar^+ laser beam and substrate heating to 300-400C. Two beam laser recrystallization was carried out on samples which were polycrystalline silicon (polysilicon) with no patterns defined and on samples with anti-reflection stripes patterned lithographically. The presence of the stripes tends to confine grain boundaries to regions underneath the stripes.

In the two-beam laser recrysallization experiments we have performed, grain sizes obtained were larger than those samples recrystallized with the Ar^+ laser alone (unpatterned samples). Moreover, for the first time recrystallization was achieved without using bulk substrate heating. Samples recrystallized using this two beam technique did not show any traces of cracking of either the polycrystalline silicon film or the SiO_2 layer beneath. Experiments performed with the Ar^+ laser alone, without a bulk substrate heater, by comparison, always resulted in cracking both in the polysilicon film and the underlying oxide layer. In these experiments melt widths of about 80 microns were obtained with a single scan of the two lasers (unpatterned samples). This is at least a factor of two greater than those obtained with a single scan of the Ar^+ laser under otherwise similar conditions. The Ar^+ laser power density required to melt the polysilicon layer was also reduced by a factor of 2. Recrystallization was achieved using the two lasers with the Ar^+ laser power at 4W which corresponds to a power density at the sample of 0.73×10^5 W/cm^2. Using the Ar^+ laser only at this power density results in no melting.

Recrystallization was achieved for the first time without the use of supplemental substrate heating with the Ar^+ laser power at 6W corresponding to a power density of 1.08 X 10^5 W/cm^2 and the CO_2 laser power at 30W, corresponding to a power density of 2.06 X 10^4 W/cm^2 without any evidence of substrate cracking. Results were also obtained without bulk substrate heating for various other combinations of power densities, but the "window" was typically smaller than that for experiments with substrate heating.[4-6]

Experiments were also performed on samples which were patterned with anti-reflection stripes. Once again, melt widths and recrystallized regions about 100 microns wide were observed with a single scan of the two lasers. Grain sizes, in particular grain widths, were limited by the dimensions of the AR pattern. Typically, grains about 10 microns wide and several hundreds of microns to 1 mm were observed. Experiments were performed with the substrate temperature reduced to 110C and then to 20C (room temperature). Similar results were obtained.

Extensive Raman characterization was performed on the above samples. This work will be summarized later in Section IV-C.

We also explored the possibility of using rapid thermal processing (RTP) to recrystallize polycrystalline silicon. We have one of the best RTP systems, a Heatpulse 410 by AG Associates. Rapid thermal systems utilize flash lamps to perform transient surface heating. To recrystallize deposited polycrystalline silicon, our RTP unit had to be pushed to the limit. In so doing we were successful in recrystallizing large areas. However, we had no control over uniformity or reproducibility at the high temperatures sufficient to melt silicon. At this point this effort can thus be considered only partially successful.

We have made an extensive comparison of the effect on laser recrystallization of different capping layer structures.[13] Three different capping layer structures were evaluated. The capping layer structures used include a 6 nm nitride layer, a combination of 64 nm nitride and 20 nm oxide layers, and 50 nm nitride antireflection periodic stripes oriented parallel to the direction of laser scanning. Electrical characteristics are measured by MOS silicon-on-insulator (SOI) test stuctures fabricated in the laser-recrystallized silicon films. Measurement of carrier mobilities, MOS interface properties, leakage currents, and ring oscillator delay times are compared for wafers having different capping layer structures. Stress in each case is characterized using a Raman spectrometer with microprobe.

Structures using 6 nm of nitride allow the widest range of laser power densities for successful laser recrystallization, but they lead to the poorest interface characteristics. Structures using the more rigid 64 nm of nitride on top of 20 nm of oxide leave behind the smoothest surface and lowest interface charge density, but the stress in the film is not as uniform as for the other capping structures. Structures using 50 nm nitride stripes resulted in effective reduction of the number of grain boundaries and effective control of their location as well as a more homogeneous stress distribution. We thus observed both improved and more uniform device characteristics for this capping layer structure.

B. Low Loss Optical Waveguides on GaAs and Si Substrates

The goal of this aspect of this research program is to demonstrate lower loss optical waveguide structures so as to make such structures more desirable for applications. For GaAs substrates optical channel waveguides can be formed by depositing several crystalline layers of GaAlAs. Varying the Al fractional composition varies the refractive index (raising the Al fractional composition lowers the refractive index). Planar waveguides are formed as four-layer structures in which the uppermost layer is a low refractive index layer corresponding to air or a very thick covering. The second layer ($Ga_{1-x}Al_xAs$) corresponds to the guiding layer and has a refractive index larger than that associated with the first and third layers. The third layer is a cladding layer ($Ga_{1-y}Al_yAs$ with $y > x$) which has the role of isolating light in the guiding layer from the fourth layer (GaAs substrate), which is very thick, has a higher refractive index than the other layers, and may be absorbing at the wavelength of interest.

An extensive modeling effort which allowed us to calculate various GaAlAs optical waveguide properties has been carried out.[7] This modeling capability has allowed us to design multiple layer structures which could then be fabricated by crystal growth techniques such as molecular beam epitaxy (MBE) or metal organic chemical vapor deposition (MOCVD).

The modeling capability described above and in more detail in reference 7 was used as a basis to design multiple layer GaAlAs structures suitable for waveguide fabrication. These structures were then fabricated elsewhere. Table I lists the samples which we have obtained including their layer structure, composition and thickness of each layer, material growth technique, and source of the material.

TABLE I

GaAlAs Multiple Layer Samples

Sample No.	Growth Technique	Layer Composition	Source
1	MOCVD	$Ga_{.9}Al_{.1}As$ (400 nm)/$Ga_{.65}Al_{.35}As$ (5000 nm)/GaAs substrate	R.D. Burnham
2	MOCVD	$Ga_{.9}Al_{.1}As$ (300 nm)/$Ga_{.65}Al_{.35}As$ (3000 nm)/GaAs substrate	"
3	MOCVD	$Ga_{.9}Al_{.1}As$ (200 nm)/$Ga_{.65}Al_{.35}As$ (3000 nm)/GaAs substrate	"
4	MOCVD	$Ga_{.9}Al_{.1}As$ (200 nm)/$Ga_{.65}Al_{.35}As$ (3000 nm)/GaAs substrate*	"
5	MOCVD	Si_3N_4/$Ga_{.87}Al_{.13}As$ (1000 nm)/$Ga_{.84}Al_{.16}As$ (6000 nm)/GaAs substrate	"
6	MOCVD	Si_3N_4/$Ga_{.87}Al_{.13}As$ (1100 nm)/$Ga_{.84}Al_{.16}As$ (6000 nm)/GaAs substrate	"
7	MOCVD	Si_3N_4/Multiple quantum well structure/$Ga_{.7}Al_{.3}As$ (6000 nm)/GaAs substrate (x = .1, 6 nm; x = .3, 12 nm; 35 repetitions)	"
8	MBE	$Ga_{.8}Al_{.2}As$ (700 nm)/$Ga_{.9}Al_{.1}As$ (600 nm)/$Ga_{.8}Al_{.2}As$ (2300 nm)/GaAs substrate*	Perkin-Elmer

*Substrate is semi-insulating, whereas substrates for other samples are n^+.

Each of the samples allows for evaluation of either a different waveguide concept or a different performance aspect. For example, sample number 7, which includes over 70 different layers, is typical of a modulator structure utilizing electro-absorption which is enhanced in a quantum well.

Starting with the samples listed in Table I, we performed photolithography to form channel waveguides in two ways. First, channel waveguides were formed by reactive ion etching an upper cladding GaAlAs layer. The degree of waveguide confinement then depended on the height of the resulting ridge. This height could be carefully controlled. The second channel waveguide structure was formed by etching a Si_3N_4 upper cladding layer to form a ridge. The lowest value of loss measured for any of these channel structures was 0.5 dB/cm at 0.82 microns wavelength for the second type structure. Waveguide confinement in the second type structure has been related to stress induced by the presence of the Si_3N_4 strip by Raman spectroscopy measurements.[10] These results will be described in IV-C. Further work in this area is still underway.

We have also used our four-layer theoretical modeling capability to make comparisons with experimental data measured earlier in this research program. The four layers in this case consist of air, SiO_2 having undergone thermal nitridation (guiding layer), SiO_2 (cladding layer), and the silicon substrate. Here attenuation of light in the guiding layer due to coupling of light to the substrate may also occur, depending on the thicknesses and refractive indices of the guiding and cladding layers. We are interested in how this value of attenuation calculated for the situations encountered experimentally compares with the measured values of loss. Such a comparison would tell us if attenuation due to substrate coupling is dominant or not.

Our measurements on low-loss planar waveguides fabricated on silicon by thermal nitridation of thick silicon dioxide layers were carried out on nine samples and ranged from .06 ± .007 to .31 ± .018 dB/cm.[14] The effective refractive index of each waveguide was measured with an uncertainty corresponding to an effective index uncertainty of ± 0.2 percent. Figure 1 displays this experimental data, tith horizontal error bars reflecting the uncertainty in effective refractive index. The solid curve shown in Figure 2 is calculated with a four-layer model for waveguides on silicon with the parameters of layer thickness and refractive indices as described by us,[14] namely, a range in n_2 from 1.67 to 1.76 and a variation of guide-layer thickness from 90 to 140 nm. The 4.7 micron silicon dioxide cladding layer refractive index was fixed at 1.464. Although the deviation of some experimental data points from the theoretical curve is significant, the correlation evident in Figure 1 suggests that substrate-coupling loss may be the dominant contribution to waveguide loss for these waveguides. If this is true, then it may be possible to achieve even lower values of waveguide loss in these waveguides by either increasing the degree of waveguide field confinement or by increasing the thickness of the isolation layer.

We have also been actively investigating formation of channel waveguides in SiO_2 by ion implantation and thermal annealing. The presence of the implanted ion locally increases the refractive index to create a channel waveguide. The use of thermal annealing then repairs the damage caused by implantation, but without eliminating the refractive index change. Work in this area has progressed to the point of samples being fabricated and tested.

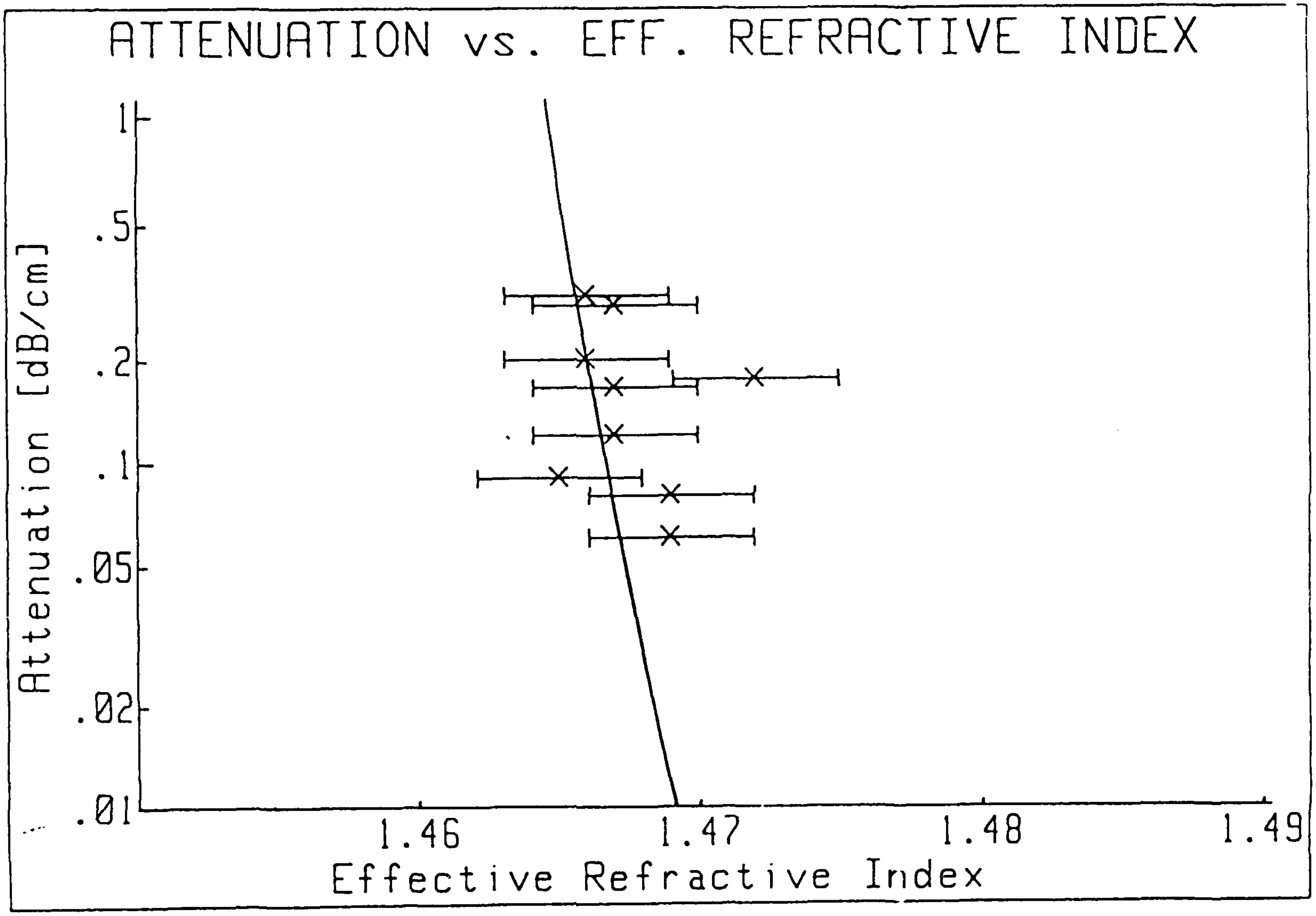

Figure 1. *Substrate-coupling* loss versus effective refractive index. The solid line corresponds to a theoretical curve calculated using the four-layer model and appropriate parameters. Experimental data points from Reference 12 are indicated by an X, while the uncertainty in effective refractive index of ± .2% is depicted by the horizontal error bars.

Losses as low as .5 dB/cm at 632.8nm wavelength have been measured for silicon-implanted waveguides. Ge-diffused waveguides have also been formed for the first time, but the losses are higher. Work in this area is continuing and will be compiled in a Master's thesis.[15]

C. Raman Microprobe Characterization

Raman spectroscopy is a familiar technique of examining inelastic light scattering from solids. The frequency shifts correspond to resonant frequencies of lattice vibration modes. The amplitude, frequency shift, and width of various peaks in the Raman spectra are thus sensitive to the masses and orientation of various elements within the material. Effects such as substitutional or interstitial doping, damage to the crystallographic structure, or strain lead to changes in the Raman spectra. The presence of a microprobe in a Raman system allows Raman measurements to be performed as a function of position. We obtained a modern Raman microprobe system (having 1 micron spatial resolution) several years ago with funding from DOD Instrumentation grant.

We have used the Raman microprobe system to characterize strain in recrystallized silicon and to characterize strain in GaAlAs multilayer waveguide structures due to the presence of Si_3N_4 ridges. For laser recrystallized silicon using two lasers (Ar^+ and CO_2) a Raman microprobe analysis revealed that the stress in the two-beam recrystallized material was about an order of magnitude less than found in Ar^+ laser recrystallized material.[5] The polarization dependence of the Raman scattered light indicated that the orientation of the recrystallized material between antireflection stripes was in a <100> orientation.[5]

A Raman microprobe investigation of GaAlAs layers with patterned Si_3N_4 stripes has been carried out.[10] The observed induced shift in the LO phonon frequency of the GaAlAs is consistent with a double-lobed lateral optical field distribution in the channel waveguide formed by Si_3N_4 stripes on GaAlAs. After rapid thermal annealing the stress-

induced shift in the LO phonon frequency was nearly eliminated and the optical field distribution assumed the usual well-confined behavior with a single peak under the Si_3N_4 stripe. In this study, we have shown that the Raman microprobe is a powerful tool for the analysis of local structural and crystalline conditions in a GaAlAs optical waveguide structure with a spatial resolution smaller than the microfrabricated features.

D. Rapid Thermal Annealing of Ti:$LiNbO_3$

The use of rapid thernal annealing (RTA) in conjunction with in-diffusion to form Ti:$LiNbO_3$ optical channel waveguides is being investigated. RTA can be used in place of furnace annealing and offers the advantages of allowing extensive computer control of temperature versus time variations which are precise, repeatable, and have a rapid time constant (several seconds). This additional flexibility over that which can be achieved with furnace annealing allows for the possibility of optimizing intermediate interactions associated with in-diffusion. Such capability could allow for fabrication of higher quality optical waveguides.

We have investigated use of rapid thermal annealing (RTA) to initiate in-diffusion of Ti into $LiNbO_3$ to form optical channel waveguides using several different RTA processes.[11,12] Each process is characterized by a different RTA temperature versus time variation followed by a common furnace heating step. One set of samples has undergone a slow ramp RTA temperature versus time variation, a second set has undergone a two step variation, a third set has undergone a very rapid ramp, and a fourth set has undergone no RTA processing. Samples processed with the fast RTA ramp of temperature versus time to 875C yielded the lowest channel waveguide propagation loss of about 1 dB/cm measured at a wavelength of 632.8 nm. Additional experiments have also demonstrated that smoother channel waveguide surfaces, and thus lower loss, can be achieved with RTA in a dry oxygen ambient as compared to RTA in a steam ambient and without any out-diffusion observable.

V. List of Program Publications

Journal Papers

C.J. Radens, B. Roughani, H.E. Jackson, J.T. Boyd, and R.D. Burnham, "Raman Microprobe Analysis of Strain Induced by Patterned Dielectric Films on GaAlAs Structures," to be published.

D.C. Cromer, J.T. Boyd, H.E. Jackson, G.N. DeBrabander, and S. Sriram, "Use of a Rapid Thermal Annealing System to Initiate In-Diffusion for Fabrication of Ti:$LiNbO_3$ Optical Channel Waveguides," to be published.

S. Dasgupta, H.E. Jackson, and J.T. Boyd, "Two-Beam Laser Recrystallization of Silicon," Journal of Applied Physics, Vol. 64, pp. 2069-2075, August 15, 1987.

W.C. Borland, D.E. Zelmon, C.J. Radens, J.T. Boyd, and H.E. Jackson, "Properties of Four-Layer Planar Optical Waveguides Near Cutoff," IEEE Journal of Quantum Electronics, Vol. QE-23, pp. 1172-1179, July, 1987.

H.E. Lu, J.T. Boyd, H.E. Jackson, and J.L. Janning, "Characterization of the Effects of Different Capping Layer Structures on the Laser Recrystallization of Silicon by Using Electrical Test Structures and Raman Spectroscopy," Journal of Applied Physics, Vol. 60, pp. 4273-4276, 1986.

A. Naumaan and J.T. Boyd, "Ring Resonator Fabricated in Phosphosilicate Glass Films Deposited by Chemical Vapor Deposition," IEEE/OSA Journal of Lightwave Technology, Vol. LT-4, pp. 1294-1303, September, 1986.

D.E. Zelmon, J.T. Boyd, and H.E. Jackson, "Low Loss Optical Waveguides Fabricated by Thermal Nitridation," Applied Physics Letters, Vol. 47, pp. 353-355, 1985.

J.T. Boyd, R.W. Wu, D.E. Zelmon, A. Naumaan, H.A. Timlin, and H.E. Jackson, "Guided Wave Optical Structures Utilizing Silicon," Optical Engineering, Special Issue on Integrated Optical Circuit Engineering, Vol. 24, pp. 230-234, 1985.

R.W. Wu, J.T. Boyd, H.A. Timlin, H.E. Jackson, and J.L. Janning, "Optical Waveguide Detection: Photodetector Array Formed on the Waveguide Utilizing Laser Recrystallized Silicon," Applied Physics Letters, Vol. 24, pp. 391-395, 1985.

Conference Presentations with Written Proceedings

D.C. Cromer, G.N. DeBrabander, J.T. Boyd, H.E. Jackson, and S. Sriram, "Fabrication of Ti:$LiNbO_3$ Optical Channel Waveguides Using a Rapid Thermal Annealing System," presented at and published in the Proceedings of the SPIE Technical Conference on Integrated Optical Circuit Engineering VI, Boston, MA, September, 1988.

C.J. Radens, H.E. Jackson, J.T. Boyd, K.B. Bhasin, J.J. Pouch, and L. Davis, "Characterization of GaAlAs Optical Waveguide Heterostructures Grown by Molecular Beam Epitaxy," presented and published in the Proceedings of the SPIE Symposium on Fiber Optics and Integrated Optoelectronics, San Diego, August, 1987.

H.E. Jackson, J.T. Boyd, S. Dasgupta, H.E. Lu, and T.D. Mantei, "Raman and Brillouin Scattering From Semiconductor Thin Films," presented at and published in the Proceedings of an upcoming SPIE Symposium on Advances in Semiconductors and Semiconductor Structures, Bay Point, Florida, March, 1987.

S. Dasgupta, H.E. Jackson, and J.T. Boyd, "Raman Scattering From Laser Recrystallized Polysilicon," presented at and published in the Proceedings of the Tenth International Conference on Raman Spectroscopy, Eugene, Oregon, September, 1986.

D.E. Zelmon, W.C. Borland, C.J. Hsieh, H.E. Jackson, and J.T. Boyd, "Near Cutoff Propagation in Low Loss Optical Waveguides Formed on SiO_2/Si Substrates," presented at and published in the Proceedings of the SPIE International Conference on Integrated Optical Circuit Engineering IV, Cambridge, MA, September, 1986.

H.E. Lu, J.T. Boyd, and R.W. Wu, "A CMOS Test Structure to Evaluate Laser Recrystallized Silicon-On-Insulator," presented at and published in The Proceedings of the IEEE VLSI Workshop On Test Structures, Long Beach, CA, February, 1986.

S. Dasgupta, H.E. Jackson, and J.T. Boyd, "Two Beam Laser Recrystallization of Silicon On An Insulating Substrate," presented at and published in The Proceedings of the Materials Research Society Meeting, Boston, MA, December, 1985.

D.E. Zelmon, H.E. Jackson, and J.T. Boyd, "Use of Thermal Nitridation to Fabricate Low Loss Planar Optical Waveguides in SiO_2," presented at and published in the Proceedings of the Second SPIE International Conference on Integrated Optical Circuit Engineering, Cambridge, MA, September, 1985.

J.T. Boyd, H.E. Jackson, D.E. Zelmon, and R.W. Wu, "Low Loss SiO_2 Optical Waveguides Formed By Thermal Nitridation and Photodetectors Formed on Waveguide Surfaces Utilizing Laser Recrystallized Silicon," presented at and published in The Proceedings of the 1985 National Science Foundation Grantee-Users Meeting on Optical Communications, Cornell University, June, 1985.

H.E. Jackson and J.T. Boyd, "Low Loss Thin Film Materials For Integrated Optics," presented at and published in The Proceedings of The American Physical Society Topical Meeting on Basic Properties of Optical Materials, May, 1985.

Conference Presentations Without Written Proceedings

S. Dasgupta, H.E. Jackson, and J.T. Boyd, "Raman Microprobe Analysis of Microcrystalline Orientation in Two-Beam Recrystallized Silicon," presented at the American Physical Society Meeting, March, 1987.

S. Dasgupta, H.E. Jackson, and J.T. Boyd, "Laser Recrystallization of Polysilicon by Simultaneous Use of Ar^+ and CO_2 Lasers," presented at the American Physical Society Meeting, March, 1986.

D.E. Zelmon, J.T. Boyd, and H.E. Jackson, "Low Loss Planar Optical Waveguides Fabricated on Silicon," presented at the Midwest Symposium on Circuits and Systems, Louisville, Kentucky, August, 1985.

H.E. Lu, R.W. Wu, J.T. Boyd, and J.L. Janning, "A CMOS Test Circuit Formed on Laser Recrystallized Silicon - On - Insulator," presented at the Joint Spring Meeting of the Ohio Section of the American Physical Society and the Southern Ohio Section of the American Association of Physics Teachers, University of Cincinnati, Cincinnati, Ohio, April 12-13, 1985.

S. Dasgupta, H.E. Jackson, and J.T. Boyd, "Laser Recrystallization of Si on SiO_2 By Ar^+ and CO_2 Laser Irradiation," presented at the Joint Spring Meeting of the Ohio Section of the American Physical Society and the Southern Ohio Section of the American Association of Physics Teachers, University of Cincinnati, Cincinnati, Ohio, April 12-13, 1985.

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S. Dasgupta, H.E. Jackson, and J.T. Boyd, "Two Beam Laser Recrystallization of Silicon on an Insulating Substrate," presented at The American Physical Society Meeting, March, 1985.

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